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Promoting the development of distributed concentrated solar thermal technology in China

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ABSTRACT

Solar energy is increasingly essential to fortify energy security and promote Chinese socio-economic development. The applications of solar thermal energy in China are mainly centralized at low and medium temperature, such as solar water heating, solar cooling and air conditioning, building heating, solar drying and solar power generating. Based on the reality in China, it is presented in this paper that China should promote the distributed concentrated solar thermal (DCST) technology, especially in the industrial field. This technology, which has the potential to reduce the high cost of DCST and overcome the intermittent output of solar energy, is discussed in this paper, as well as how to put DCST technology forward and enlarge scale deployment in China. Finally, it is hoped that suggestions in this paper could be helpful to the researchers, designers and policy-makers who are involving in this field.

Contents

1. Introduction

Energy industry plays a critical role in socio-economic development and improvement of people's living standards. A reference scenario of economic activity and energy consumption in China is illustrated in Ref. [1], which shows that China's total energy consumption will come to 4.6 Gtce by 2020, and 6.2 Gtce by 2050, respectively. It is well known that most of the Chinese energy is from fossil fuel energy, and coal is by far the most important component [2]. Although China has abundant coal resources, the pollution caused by using it has raised serious concerns nationwide. Therefore, renewable energy, which has characteristic of wide

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distribution of resources, great utilization potential, less environmental pollution and reusable, could be an promising alternative to maintain the harmony between human beings and nature [3].

In fact, China has already taken intensive efforts to promote research, development, demonstration and commercialization of renewable energy technologies over the past years. The three key programs (TKPs) in China, the National Basic Research Program (973 Program), the National High-tech R&D Program (863 Program), and the National Key Technology R&D Program, have been focusing on the research and development of renewable energy. During the 11th Five-Year Plan Period (2005–2010), the Chinese government has paid much more attentions on science and technology of energy and climate security. At the same time, the government has taken substantial efforts to energy legislation for sustainable energy system transformation. Renewable Energy Law and Circular Economy Law have taken effects since 2006 and 2007, respectively. After being amended in 2007, Energy Conservation Law appears more specific and applicable. Some other laws such as Mineral Resources Law, Coal Industry Law and Electric Power Law are under revision [1]. In March 2011, Central Committee of the Communist Party of China's (CPC) approved the China's 12th Five-Year Plan (FYP) for National Economic and Social Development (2011–2015). The 12th FYP formulates that China pledge to have 16% of its total energy consumption coming from non-fossil fuels by 2020 (from 8.3% in 2009 to 11% approximately by 2015). This plan also contains significant supports for renewable energy development, such as nuclear energy, wind energy and solar energy.

2. Solar thermal energy situation in China

China is vast in territory with a wealth of solar energy resources. All the land surface receives an annual solar radiant energy of 1.7×10^{12} tce, Of which more than two-third receives an annual radiation of more than 5.02×10^6 kJ/m^2 and a sunshine time of more than 2000 h. Qinghai-Tibet Tableland, in particular, receives the most intense radiation [4]. In China, the solar thermal utilizations are mainly centralized on the low and medium temperature thermal applications, including solar water heating, solar cooling and air conditioning, solar building, solar drying and solar power generating [5].

2.1. Solar water heater

Solar water heating is so far a dominant and widespread solar thermal technology in China. Since 1980, solar water heaters based on this technology has been rapidly boosted with an annually average growth of 30% [5]. There are three types of solar water heaters dominating the market, including batch, flat-plate, and the all-glass vacuum tube. A typical application using solar water heaters is located in Kunming, Yunnan Province, where almost all the residential buildings are equipped with solar water heaters. After 30 years' development, five production bases for solar water heaters have already formed in Beijing, Ludong, Taian, Yangzhou and Haining, respectively. So, China has already become the largest producer and user of solar water heater around the world. In 2010, a total amount of 5 million m^2 of solar water collectors has been put into practice with a total value of 1.2 billion dollars nationwide [6]. Moreover, Chinese government has strengthened legislation and policy-making. Technical code for solar water heating system of civil buildings has taken effect in 2006 [7], and the first compulsory national standard on solar water heating industry, minimum allowable values of energy efficiency and energy efficiency grades for domestic solar water heating systems, is formulated and will be put into practice at the end of 2011. In this newly standard, solar water heating products are to be classified in three levels, in which products of level 1 are in the highest energy efficiency, and those meeting the demand of level 3 are allowed to sell in the markets. However, the standard need to acquire the World Trade Organization' Certification, for it is mainly based on development of solar water heating industry in China, rather than the international standards [8].

2.2. Solar refrigeration and air conditioner

Solar cooling is considered as a very attractive application, for it can compensate the needs of cooling caused by the solar radiation. In China, the research and development of solar cooling systems have been originated since the 1970s, and most of those works were mainly focused on the solar absorption refrigeration systems in the early stages, and a series of solar absorption systems have been successfully developed. For example, a large-scale solar absorption refrigeration and hot water hybrid system were built in Rushan, Shandong Province [5]. Rapid development has been made in solar solid adsorption refrigeration. Several kinds of solar ice-maker have been successfully developed in the 1990s–2000s. More recently, a novel open solar absorption refrigeration system using air as heat carried medium has been experimented in Dalian University of Technology. And energy storage by using solar refrigeration system has been studied in Central China University of Science and Technology. Another novel refrigeration system with solar and gas being energy sources has been presented by Dai and Wang [9]. Moreover, the solar ejector refrigeration system has been investigated by Wang and Shen in Dalian University of Technology [10].

2.3. Solar building integration

Investigations on solar building integration technology started in the early 1970s, and at the first stage, most of those investigations were mainly focused on passive solar house, especially in northwestern China. Then, the use of passive solar greenhouses for agricultural production and flower cultivation has also been increased nationwide. In China, energy consumption in buildings accounts for approximate 30% of the total energy consumption, and now this proportion is soaring with improvement of people's living conditions. Hence, solar passive buildings are considered to have a potential market in the near future. Also, some illustrative buildings with integrated solar water heaters have been put into practice. Taking Shanghai for example, the equivalent solar collecting area reached to 2,500,000 m^2 by 2009, in which both solar water heating and air source heat pump water heating systems were integrated [11]. An ideal opportunity to carry out renovation with roof-integrated solar collectors is in combination with the rebuilding of apartment roofs from flat to incline. Solar water collectors have become a significant symbol of green buildings. For instance, in buildings of Beijing Olympic city, solar collectors have been provided about 90% of domestic hot water requirements [12].

2.4. Solar energy for industry

For industry, solar energy should be utilized at a higher working temperature and a higher efficiency in energy transfer, along with more suitable energy storage system. To date, there are more than 100 sets of solar dryers are being worked throughout China, which are mainly aimed for the drying of grain, wood, vegetables, meat products and medicinal herbs [5]. As a successful example, a large-scale solar-roof heating system for industrial application was built in Shangshu Dongfang Yinran Factory, with a total aperture area of 10,000 m^2 [13].

Solar thermal power system is a technology for electric power production by using of concentrated solar thermal (CST). Several companies in China have been developing larger commercial solar thermal power plants in the 11th Five-Year Plan period through cooperation with other countries. Research on solar thermal power systems and related components has always been also greatly supported by Ministry of Science and Technology of China. In 2005, the first demonstration CST power tower with a capacity of 75 kW was built and connected national grid successfully in Nanjing. By December 2010, another power tower with a capacity of 1 MW in a demonstration project called DAHAN was on operation at the Yanqing district of Beijing, which is the second power tower demonstration project in China [13]. This project was supported financially by the Ministry of Science and Technology and the Beijing Municipal Science and Technology Commission on the purpose of learning technology and testing components of the power tower. Solar Millennium, one of European leaders in CST parabolic trough technology, established a project development company in Hohhot, Inner Mongolia in August 2007. This joint-venture has recently concluded feasibility studies on a 50 MW size parabolic trough power plant for the region. Preparations are also under way for the construction of a 50 MW concentrating solar power plant in Gansu Province in northwestern China [14].

Increasing attentions from government and authorities enable the policies and national standards on solar energy for industry. An newly national standard, technical code for solar water heating system of industrial application, is reported to be In the draft and expect to come into force in the next few years. In 2007, mid- and long-term development programming for renewable energy promote solar thermal power demonstration projects with a total capacity of 50,000 kW until 2010 and 200,000 until 2020 at extensive deserts and Gobi in provinces like Neimenggu, Gansu and Xinjiang [15]. However, the total installed capacity is likely to increasingly raise in renewable energy development plan in 12th FYP, which is to take into effect later in this year [16]. Moreover, in May this year, Adjustment Catalog of Industrial Structure firstly lists solar thermal power at the top of new energy catalog which will be greatly supported by Chinese government [17].

To date, the installed capacity of solar thermal application in China has reached a total of 39,000 MW. However, solar water heaters, even using vacuum tube technology, can only produce at most 70–80 °C hot water in summer, and 40–50 °C in winter. Although this temperature range is suitable for residential water heating and sanitary usage, it can hardly meet the requirements of high-temperature heat steam for industry process and power generation. Therefore, the use of concentrating system by effectively improving solar energy density to produce high temperature heat steam turns out to be a critical imperative for energy supply [18].

3. Opportunities and challenges of distributed concentrated solar thermal application in china

CST systems use lenses/mirrors and tracking systems to focus a large area of sunlight onto a small area. The concentrated light is then used as heat or as a heat source for a conventional thermal usage. A wide range of concentrating technologies exist, including the parabolic trough, dish, concentrating linear Fresnel reflector, solar chimney and solar power tower [19]. Based on this traditional system, a novel technology, distribute concentrated solar thermal (DCST), is designed in a smaller collector size and lower operating temperatures, usually below 315 °C. This technology is expected to use at modular fields or rooftop installation, for they are easy to avert severe conditions like high winds, snow and humid deployments [20].

3.1. Benefit to sustainable industrial development

Rapid growth in both industry and service sectors is creating an unprecedented opportunity for technological innovation and application of DCST. Energy demand in industry sectors, which accounts for more than half of total energy consumption in China, is the major driver of electricity and heat generation capacity addition [21]. And more than half of this demand is consumed by heat requirement of industrial process. It is reported that industrial demand for energy is expected to increase 3.2% per year over the period of 2010–2030 [22]. Therefore, DCST development is of great interest in industrial cities where both energy demands of civil and industrial sectors can be integrated into the same centralized distribution system.

3.2. Important part to national smart grid

Recent development of distributed electricity generation is shifting the production of electricity from large centralized power plants to local generation units. In this light, a promising direction for improving the local energy production is to enable the integration of distributed energy resources combining production of different energy vectors into a comprehensive distributed multi-generation (DMG) framework [23]. Therefore, China is to invest a total of $7.3 billion on smart grid technology in the coming year. In fact, China government adds more investments than ever before on smart grid technology for electricity generation. The smart grid, with an ability of switching automatically among multiple sources, will be a key enabler for the use of renewable energy sources such as DCST. Indeed, private firms and provincial governments across northern and eastern China are prepared to build several 10 GW solar generation bases. About 15% of China's total electricity generation estimated at 4200 GW will be expected in renewable energy by 2020 [24]. So, power generation from DCST will be anticipated an important component for the national smart grids.

3.3. Crucial to China new social countryside construction

As the national economy improves, energy consumption in the rural has been shifting tremendously. A reasonable method for rural energy supply is a significant part of the sustainable development in China [25]. The main aim of a new socialist countryside is to improve people's living standard in the rural. As a result, this will inevitably cause a large increase of energy consumption in the rural. Recently, the rural energy consumption has been increasing at an accelerating speed [26]. In order to realize the new socialist countryside strategy, we should not take the traditional road using in urban in which fossil energy is depleted shapely, but make as much as possible to increase the use of renewable energy such as solar energy in the broad countryside to relieve stress of energy consumption. Nevertheless, solar energy could be a promising option to effectively supply cooling and heating for houses throughout the countryside. Moreover, it is also suitable for other special users, such as outpost frontier strongholds, remote communication stations or hotels in nature reserve [27,28].

3.4. Prospect of DCST technology in China

China is already a world leader in terms of solar thermal heating and is currently a significant player in solar PV manufacturing. If the transition from solar thermal heating and solar photovoltaics to concentrating solar thermal is possible, DCST deployments could be the catalyst needed. Chinese Ministry of Science and Technology has identified DCST as an important research area in the Summary of National Mid & Long-Term Science and Technology Development Principles (2006–2020) [29].

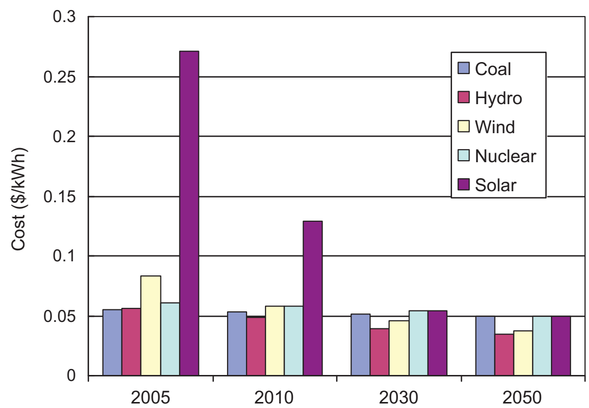


Fig. 1. Cost of primary energy consumptions over next decades.

Two main major barriers impede the widespread adoption of DCST system on a large scale. The first one is its high cost compared to traditional energy sources under current market conditions. The second is that solar energy source appears intermittent and fluctuant in power output. A system that can solve these problems has the potential to achieve significant adoption.

One technology which has the potential to overcome these challenges above is a DCST technology for electricity generation with a Stirling engine and integrated energy storage. Though the dish engine may still have much to improve, its small capacity, modular design and significant potential for decrease in capital costs (estimated at 57%) make it a potential solution in building a decentralized power infrastructure in China. Researchers have achieved a capacity cost of $1/W by DCST technology, which generally is considered as a major milestone to make solar energy more competitive in cost by employing low-cost materials, simple manufacturing, and careful design. It is estimated that the cost of solar energy application will be greatly lowered over next decades, as shown in Fig. 1. Moreover, it is shown in Fig. 2 that inherent thermal energy storage provides a means of generating continuous and stable power output [30].

The '863' program, solar thermal power technologies and demonstration systems in 2006, and the '973' program, fundamental research of large-scale and high-efficiency solar thermal power production in 2010, has been successively launched by Institute of Electrical Engineering, Chinese Academy of Sciences [31,32]. Also, a prototype DCST system, which was designed with multiple facets for concentrated solar energy, is presented. In this system, a stand-alone parabolic reflector with low-cost micro-facet solar concentrator is proposed. A large number of small flat mirrors are situated in a parabolic surface to approximate a large parabolic mirror. Low-cost commercial flat mirrors can be used for manufacturing such concentrators [33]. Geometrical analyses show that this concentrator will have a concentration rate of some hundreds of suns. Rough estimations show that the cost of the concentrator should be $60/m^2 of concentrator surface. This solar concentrator can substantially reduce the cost of DCST system and will permit their application for industrial and civil filed, such as individual home energy service.

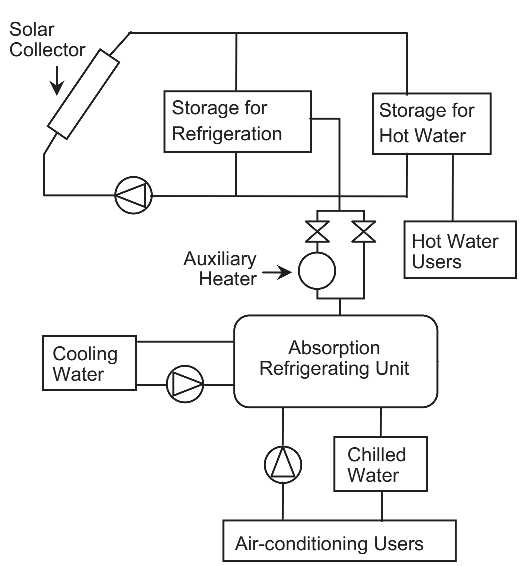


Fig. 2. General scheme of solar thermal energy storage system.

4. Suggestions to the development of DCST

There are significant potentials for large-scale deployment of the DCST technology in China, and it will be critical for its development in the next few decades. Much more measures should be taken to put the DCST technology forward and enlarge scale deployment [4,15].

4.1. Enlarge investment on DCST research and development

As we all know, China is now the biggest solar heater supply in the world, and Chinese government has invested much on low temperature application field. However, the temperature range of the application is limited to about 50–70 °C, which can hardly meet the requirement of medium temperature for industry process and other field. A small proportion is invested in technical research and development of DCST with more high temperature, which is also a technique-intensive and fund-intensive industry. Therefore, the government should provide sustainable support financially to the technical research and project development stage by stage, so as to reduce investment risk of individual enterprises, and enhance their activity in participating the technical research and development. Only in this way, it is anticipated to accelerate the localization and state-made process of DCST equipment manufacture and to promote the sustainable and healthy development of DCST industry in China.

4.2. Enhance the policy innovation and ensure the policy effective

Supports from the government is originally contributive to the development of DCST. Both national and local governments should make concerted efforts to form a complete and powerful policy system. Several reinforcing measures should be taken into consideration, such as consistent policy approval to conduct investment towards DCST industry, promotion of training of engineers and technicians on DCST, energy efficiency and CO_2 compliance in upstream industrials, and free communication of expertise, know-how, novel ideas and experience in CST sector. Some policies related to China's renewable energy tend to be soft in their transmission process, leading to the trouble that the function of policies is sometimes undermined. So DCST Development Offices should be organized by both national and local governments, which would be in charge of policy implementation and industrial dynamic management. Meanwhile, independent supervising committees should be established to monitor policies making and implementation. Certainly, these teams should report to the public and feedback their information to their supervisors from lower levels of units.

4.3. Establish mechanism to overcome financial bottleneck

Lack of appropriate market incentives and policy supports, the development of concentrating solar technology is still limited to a few numbers of small-sized pilot projects. Large-scale deployment will need supports of national policies, including establishing the relevant investment and financing mechanism, because most of domestic enterprises have not invested enough in this field. In order to formulate a long-term and effective development mechanism for DCST, we should make enormous efforts on exploring DCST capital market. Moreover, most investors on power and heat production in China are unfamiliar with DCST technology, though DCST is ready for large-scale and rapid deployment. Public resources would be partly sufficient to meet the financing requirements of DCST technology, so cooperation between the public and the private is urgently needed to boost DCST industry.

4.4. Promote energy price and institutional reform

China should promote the energy pricing reform more quickly, because the government take a heavily burden to compensate for power generation to keep its price at a low level. The electricity price is regulated by the regulatory authorities through administrative approach and may not necessarily reflect the real cost of power generation, let alone the externality costs caused by influence on environment. In many circumstances, some industries benefit from specific power allocation base upon agreement with local government. Therefore, electricity and heat generated by DCST could not be enough competitive if the final energy prices are low. And consumers do not receive any unbiased price signals of heat consumed, this pricing system may result in huge energy waste and inefficient management of energy supply system. So, no private investors would take a risk in developing the DCST unless a reasonable electricity tariff, transparent regulation and relevant institutions in charge are properly established. In short, the existing regulatory institutions of power and heat generation require fundamental reform to pave the way for a large scale development of DCST in the coming years.

5. Conclusions

Energy industry is of critical importance to socio-economic development and improvement of people's living standards. To relief the pressure of energy and environment, renewable energy could be an important energy source which helps to maintain the harmony between human beings and nature. China is blessed with abundant solar resources, much more attention should be taken to make full use of solar energy, especially in the low and medium temperature thermal applications.

Currently, most solar water heaters in the market can only deliver at most 70 or 80 °C hot water in summer, and 40–50 °C in winter. Although this temperature is suitable for residential water heating and sanitary usage, it can hardly meet the requirements of high-temperature heat steam for industry process and power generation. Therefore, concentrating solar energy system turns out to be an effective energy supply. Considering the reality of China, it is presented in this paper that China should promote DCST technology, especially in the industrial field and building field. To cut the production cost and overcome fluctuating output of solar energy which are two barriers in development of DCST on a large scale, two prototypes DCST technology are discussed. One is a distributed concentrated solar thermal electric generation system with a Stirling engine and integrated energy storage. The other is a DCST system adopting multiple facets for concentrated solar energy, which has a stand-alone parabolic reflector, with low-cost micro-facet solar concentrator. Finally, suggestions on how to put DCST technology forward and enlarge scale deployment in China is recommended, including enlarging investment on DCST research and development, enhancing the policy innovation, ensuring the policy effective, establishing mechanism to overcome financial bottleneck and promoting energy price and institutional reform.

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